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ORIGINAL PAPER

Potential of utilization of the residues from poplar plantation for particleboard production in Iran

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Abstract: The composite board industry in Iran is obliged to use residues from forest operation as well as wood industry for competing with paper industry because of shortage of wood. In the present study we investigated the residues from poplar plantation used for particleboard production. Three kinds of wood materials, poplar branches, small diameter poplar wood (3−8 cm) and beech wood, were used in the experiment of particleboard production. The results demonstrated that the characteristic of particleboard made from poplar branches and small diameter wood is comparable to that made from mature beech wood. To avoid too much residual acid in the final board, the properties of boards produced with 1.5% hardener at 175ºC press temperature are acceptable, although the properties of particleboard produced with 2% hardener were higher than were higher than that of the board produced with lower hardener (1% or 1.5%).. The MOR, MOE and IB of particleboard made from branches were measured as 14.57, 2015, and 1.32 MPa, respectively, while The MOR, MOE and IB of particleboard produced from small diameter poplar wood were 19.90, 2199, and 1.86 MPa, respectively. The thickness swelling of boards made from branches after 2 and 24 h immersion in water was 20.14% and 31.26%. The utilization of branches and very small diameter wood of poplar is recommended for the survival and developments of particleboard industry in Iran.

Keywords: poplar; branches; short rotation; particleboard; strength properties

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Introduction

The intention of wood processing operations was changed from burning wood residues to generate energy toward utilizing such residues as raw material to produce value added products during the 1940's and 1950's. Particleboard production was the first choice, since any kind of wood wastes can be used and its homogenous properties made it suitable for variety of applications. The successful development and manufacturing of particleboard is attributed to utilization of low cost residues as well as development of efficient resins. Particleboard received global acceptance and soon enjoyed rapid growth, even though the initial development and growth was slow. During the course of particleboard development, the raw material supply changed from wood processing residues (edging as well as planer shaving) to residues from forestry operation. However, since the world is facing severe shortage of wood supply, attention is toward the utilization of non-wood fiber supplies such as agricultural residues (bagasse and wheat straw) not only in forest deficient countries but also in forest rich countries (Meinlschmidt et al. 2008; Aguilar & Yglesias 2008; Pan et al. 2006; Wang & Sun 2001; Xu,et al. 2005; Kalagcioglu & Hemli 2006, Jahan Latibari et al. 1996; Natalos & Grigoriou 2002; Nemli et al. 2003), but interest in wood still prevailing.

Utilization of urban wood wastes, which is sometimes called urban Jungle, was also investigated (Pinto et al. 2008; Yang et al. 2007; Yu et al. 2007). Meanwhile, many studies were conducted on application of alternative wood species and their residues (Xu & Suchsland 1998; Van Niekerl & Pizzi 1994; Blanchet et al. 2000; Pedieu et al. 2008; Nourbakhsh 2008).

In the course of research and development for particle board production, each country tries to utilize its domestic and available lignocellulosic raw material. Although particleboard industry has been well established in different locations in Iran and board production has been enjoying fairly good growth (Table 1), the particleboard industry suffers from shortage of wood and

is obligated to use residues and underutilized raw material. In this era, Iran is fortunate to possess the possibilities of poplar tree plantation in mountain regions around the country, as well as fast growth hybrid poplar trees in plains. These plantations are intended for timber production and commonly used as poles for rural housing, wooden box manufacturing as well as raw materials of pulpwood. Poplar timber production for either poles or pulpwood generates vast quantities of very small diameter, unused branches. Field measurements indicated that only in three western provinces of Iran, there are almost three million cubic meters of standing poplar timber. In addition, short rotation poplar plantations are under study and such operation yields high volume of very small diameter wood which can be used for board production (Table 2).

Table 1. Particleboard production in 17 small scale plants in Iran

Year	2004*	2005	2006	2007	2008
Production (m^3)	590444	599505	651960	717263	732105

*Iran calender year starts from March 20 of European year. 2004 means from March,24,2004 to March,20,2005.

Table 2. Yield and bark content of three year old poplar colones **

Poplar colones	Yield (BD $t{\cdot}ha^{-1}{\cdot}a^{-1}$)	Bark Content (%)
Populus euramericana,costanso	28.75	7.5-9
Populus euramericana, 561.41	23.04	8-10
Populus euramericana,triplo	21.93	9-9.5
Populus euramericana,verniubensis	19.65	8-10
Populus euramericana, marilandica	18.91	7.5-10
Populus euramericana,I-214	17.13	8-10
Populus deltoides, 77.51	16.41	8-9
Populus trichocarpa	14.98	7.5-10
Populus nigra, betulifolia	18.86	9-10

** Source: Nourbakhsh 2008

In the course of extending the *particleboard* production, Iran needs to utilize uncommon raw material. The objective of this work was to investigate the characterization and development of conventional and homogenous particleboard from unutilized poplar branches and small diameter wood grown in western Iran.

Material and Methods

Materials

Poplar tree branches (diameter less than 3 cm) and small diameter poplar wood (diameter between 3 and 8 cm) were collected from *Populus nigra* plantation in Western Iran. Beech wood with diameter > 10 cm was obtained from local board production plant. Samples of branches, small diameter stem and beech wood were debarked manually for bark content measurement and the bark content was determined as 22.96%, 16.74% and 10.31% respectively for branches, small diameter stem and beech wood.

Urea-formaldehyde resin with 63% solid content, 1.263 g/cm^3 the specific gravity, 68 s viscosity, 80 s gel time, and 7.54 pH was supplied by local resin manufacturing plant. Reagent grade ammonium chloride was used as hardener.

Particle generation

All residues were separately chipped using Pallmann PHT 120×430 drum chipper and then were flaked using Pallmann PZ8 ring flaker. Particles were dried to 3% moisture content utilizing laboratory, rotary drum dryer. Dry particles were screened and undersize and oversize particles were separated. Accepted particle were kept in polyethylene bags for use.

pH and buffering capacities of different particles were measured according to Johns and Niazi (1980) and the result is summarized in Table 3.

Board Making and Testing

Particles were blended with 10% resin (dry basis) and three levels (1%, 1.5% and 2%) of hardener and then were formed using wooden mold. Target density and thickness of board were determined at 0.7 g/cm^3 and 15 mm. Mats were pressed in laboratory press for 6 min at 25 bar specific pressure, 5 mm/s closing speed. Three press temperatures of 165°C, 170°C and 175°C were used for board pressing. At the end of press cycle, boards were discharged and cooled to room temperature. Testing specimens were prepared from each board according to relevant EN standards. Four boards were made for each combination of variables.

MOR and MOE were measured according to EN 310/1996, internal bond, EN319/1996 and dimensional changes EN 317/1996 standards.

Results

The physical and chemical characteristics of wood may affect the adhesive bond forming performance and particle generation. pH value, buffering capacity, and particle size distribution of poplar branches, beech wood and the small diameter wood were measured after flaking and the results are presented in Tables 3, 4 and 5. The pH value and alkaline buffering capacity of beech wood was higher than that of poplar wood, while the acid buffering capacity of poplar branch wood was higher than other kinds of wood. Small diameter poplar wood generated longer flakes than other two woods, but the width and thickness of flakes were almost identical. Particle size distribution shows that harder beech wood generated smaller particles compared to less dense poplar wood.

The measurements of strength and dimensional stability of the boards made from the three kinds of wood are plotted in Figs 1−5. Each characteristic of all boards are plotted in one figure to facilitate comparison of the results obtained from each material. As shown in these figures, the small diameter poplar wood had

highest strength values followed by poplar branches. Beech wood produced lowest strength values. On the contrary to strength properties, the dimensional stability of boards made from beech wood was lower than that of other kind of materials.

Table 3. pH and buffering capacities of different particles

Material	pH	Acid buffering capacity ml 1 N NaOH	Alkaline buffering capacity ml 1 N H_2SO_4
Poplar branches	5.7	0.0625	0.125
Small diameter wood	5.8	0.0255	0.0575
Beech wood	6.41	0.0590	0.0880

Table 4. Length, width and thickness of different particles

Material	Length (mm)`	Width (mm)	Thickness (mm)
Poplar branches	18.86	4.53	0.39
Small diameter wood	25.32	5.78	0.36
Beech wood	19.45	4.60	0.41

Table 5. Particle dimension and classification of different materials

Material	< 0.4 mm %	0.4-1 mm %	1-2 mm %	2-4 mm %	>4 mm %
Poplar branches	4.54	8.7	30.65	21.8	34.31
Small diameter wood	3.75	5.32	2.14	19.39	48.4
Beech wood	4.38	16.41	23.21	25.56	30.45

Discussion

The length and width of the particles from poplar branches were lower than that of the particles from small diameter poplar wood, but almost similar to beech wood. Of course, it was anticipated to reach smaller dimensions for particles from branches, but the smaller dimensions for particles from beech wood was to some extend unexpected. However, if the identical particle generation settings were used, then it can be anticipated that, harder beech wood will produce smaller particles (Table 3). Particle classification also indicates that smaller diameter poplar wood produced larger particles, with a higher percentage of the particles >4 mm (Table 5).

The results of strength and thickness swelling measurement are plotted in Figs. 1−5. Each value in Table 6 and Figs. 1−5 is the average of 16 measurements (four replicate boards for each combination of variables and four sets of specimens from each board).

Boards made from small diameter poplar wood produced higher strength followed by the board from branches. In similar board making conditions, beech-wood boards showed lowest strength. It was expected that mature beech wood would produce higher strength than either small diameter wood or poplar branches that contain higher amount of bark and juvenile wood; however, the strength development of branches was higher than that of beech wood which is a common raw material for particleboard production in Iran. It is anticipated that the higher value in strength is related to larger particles, lower density of poplar wood as well as suitable buffering capacity of poplar woods. However, the impact of juvenile wood and bark content should not be underestimated. Higher strength values for boards made from small diameter poplar wood were observed compared to branches.

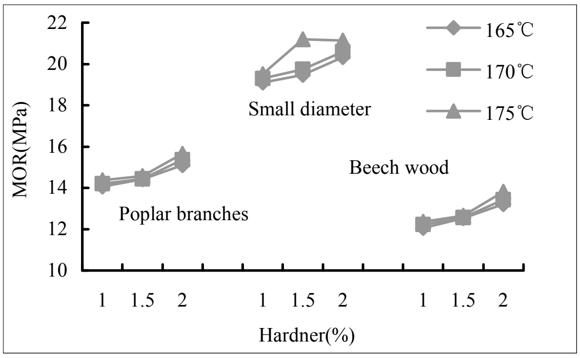

Fig. 1 The influence of different raw materials, hardener dosage and press temperatures on Modulus of Rupture (MOR) of the particleboard.

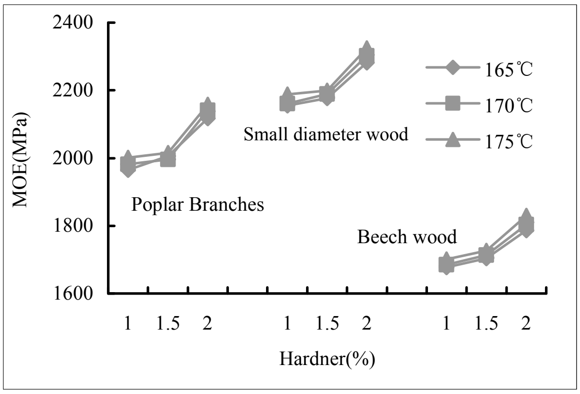

Fig. 2 The influence of different raw materials, hardner dosage and press temperature on MOE of the particleboard.

Our results indicate the positive influence of either consumption of more hardener or higher press temperatures on MOR, MOE and IB. However, the influence of these variables on MOR, MOE and IB is not identical and some variations were observed. Higher press temperature improved MOR, MOE and IB of the boards, indicating that for 15-mm thick boards, at lower temperature (165˚C), sufficient heat is not transferred to the core layer. Consequently, the strength development is not favorable. However, when the press temperature was raised to 175˚C, more softening surface layer particles were found, and this behavior caused higher MOR and MOE. Obviously, at higher press temperatures, sufficient heat energy is transferred to the core layer of the mat and resin curing and bond formations advanced. This phenomenon is accompanied by higher internal bonding. The

influence of press temperature on strength values is statistically significant at 99% level. The positive effect of press temperature on thickness swelling was observed and thickness swelling both after 2 h and 24 h immersion in water was improved.

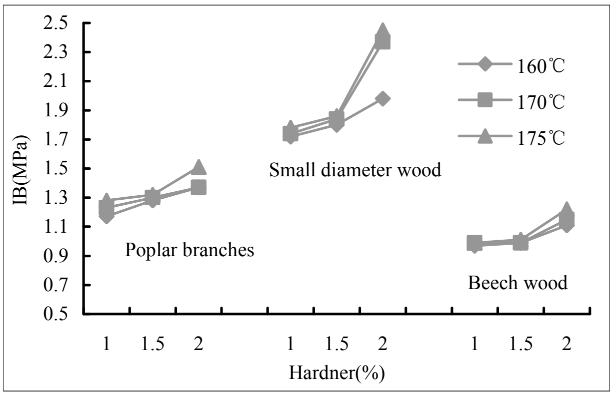

Fig. 3 The influence of different raw materials, hardener dosage and press temperatures on Internal Bonding (IB) of particleboard

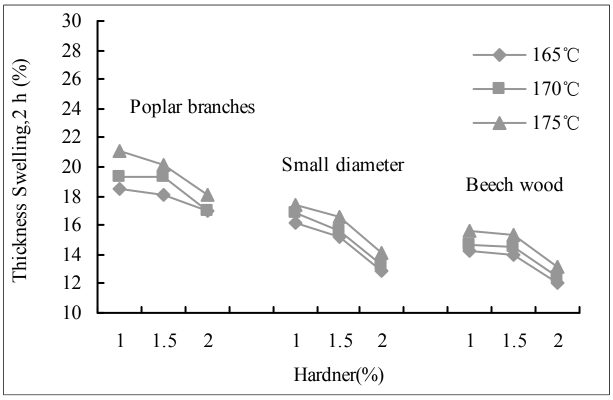

Fig. 4 The influence of different raw materials, hardener dosage and press temperature on thickness swelling of the particleboard after 2 h soaking in water

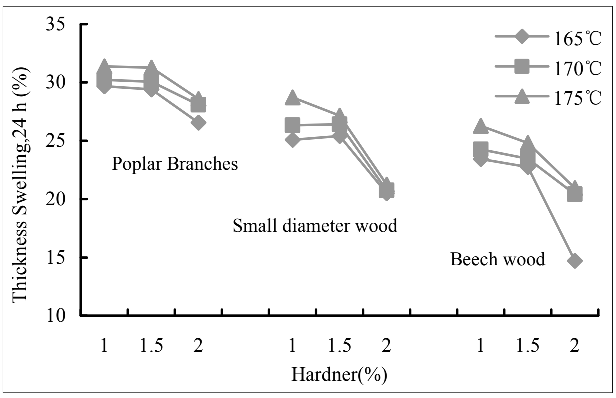

Fig. 5 The influence of different raw materials, hardener dosage and press temperatures on thickness swelling of the particleboard after 24 h soaking in water

Apparently, hardener dosage is more influential especially on MOE and IB of the boards made from small diameter poplar wood (Figs. 2 and 3). Although higher dosage of hardener increased all strength values, the development of MOE and IB is more evident at addition level of 2% hardener, especially at higher press temperatures, as compared to other two dosages (1% and 1.5%). The influence of hardener dosage on strength properties was statistically significant at 99% level. UF resin curing chemistry requires a balance between the buffering capacity of resin and wood particles. As the buffering capacity of wood lowers, then sufficient acid may not be available from wood and consequently the curing of the resin will be slow, which causes longer pressing time. In such condition, producer ought to add more hardener to provide enough acidity in the system to reduce the press time. The buffering capacities of small diameter wood were lower than that of other two materials, indicating the need for higher amount of acid to cure UF resin. Therefore, it is expected that, higher dosage of hardener will work better than lower amounts. Although the results revealed that higher dosage of hardener provided better condition for strength development, to avoid extra possible residual acid in the board and consequent deteriorating effect, producer can reduce the hardener dosage to 1.5% and simultaneously achieve needed strength (Table 6). Resin producers should develop UF resin with suitable buffering capacity to avoid too much hardener requirement.

Wood raw material shortage around the globe necessitated extensive research activities to utilize non-conventional, non-wood resources. Europe and North America are fortunate to possess sufficient wood, but as Table 6 shows, research in non-wood application in particleboard production in Europe is probably for two reasons; provide supplementary raw material and export know-how and technology (Meinlschmidt et al. 2008; Ratnasinggan et al. 2008: Grigoriou, 1998; McLauchlin & Hague 1998; Hague et al. 1997). However, in other regions especially in Asia, because of shortage of wood raw materials, some particleboard production factories will be forced to shut down. In such tense situation, one viable alternative will be biomass produced from fast growth species like poplar trees, including both residues generated from plantations for timber production and short rotation forestry (cappic). Table 6 provides complete comparison of the results obtained by different research groups on the application of non-wood as well as non-conventional raw material in particleboard production. In some case, wheat straw used as raw material for production of board shows superiority (Grigoriou, 2008); however, we should noticed that to produce high properties of board using wheat straw will cost much and isocyanate resin is even not available. It is not easy to reach acceptable properties for board production from wheat straw (Hague et al. 1997). Our results revealed that the properties of particleboard produced using poplar residues are superior to spruce and poplar wood (Meinlschmidt et al. 2008) and wood (industrial mixed species) (McLauchlin and Hague 1998), but comparable to poplar short rotation cappic (Hague et al. 1997).

Conclusion

Branches amount to almost one third of total volume of standing tree. The particleboard produced using poplar branches as well as small diameter stem of poplar (diameter less than 8 cm) are superior to those made from mature beech wood, in terms of strength and thickness swelling, and meats the EN requirements. The present study indicates that establishing small scale particleboard plants in rural areas of western Iran can be foreseen as alternative to plants in northern region with narrow strip of hardwood forests.

Table 6- Performance and potentials of alterative raw materials for particleboard production

Raw Material	MOR MPa.	MOE MPa.	Internal Bond MPa.	Thickness Swelling 24 hours (%)	Ref.
Poplar Branches[1]	14.57	2015	1.32	31.26	Present work
Poplar (Small Diam.)[1]	19.90	2199	1.86	27.16	//
Beech wood[1]	12.65	1725	1.01	24.81	//
Oil palm biomass[2]	18	2000	0.8	11	Ratnasigan et al. 2008
Wheat straw[3]	31.57	-	0.98	19.7	Grigoriou 1998
Wood (Ind.Mix)[4]	12.8	2100	0.8	23.5	McLauchlin & Hague 1998
Miscanthus[4]	14.4	2450	0.48	17.5	//
Flax shives[4]	11.9	2250	0.24	35	//
Hemp[4]	13.8	2000	0.6	27	//
Poplar (SRC) [5]	13.5	2100	1.1	17.5	Hague et al. 1997
Wheat straw [5]	11	2120	0.28	31.5	//
Rapeseed straw[5]	13.2	2150	0.52	23.5	//
EN 312 type 2	13	1600	0.35	-	

1- 10% UF resin; board density: 700 kg/m3; press tem.:175 C; 1.5% NH4Cl (based on resin solid)

2- 8% UF resin; board density: 700-750 kg/m3

3- 5% UF &5% PMDI; board density: 700 kg/m3

4- 12% UF resin; board density: 650 kg/m3; 1.5% NH4Cl (based on resin solid)

5- Short rotation cappic; 8% UF resin; board density: 650 kg/m3 ; 0.6% wax

Wood composite board industry accepted the superiority of MDF over particleboard and such thoughts caused particleboard to be replaced by MDF in common applications. However, particleboard production offers the best alternative to use any wood residues. Larger scale raw material production from short rotation forestry and fast growth trees will be viable alternatives not only for Iran but for all regions in Asia.

Our results based on laboratory trial of particleboard production indicates that more than normal amount of hardener generates higher strength values; however, for large scale production, resin formulation especially resin buffering capacity must be adjusted, so that lower percentage of hardener (1% or lower) can be used in particleboard production.

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